Solar System Exploration Division, GSFC Code 690

High-resolution lunar topography from Kaguya Terrain Camera and Lunar Orbiter Laser Altimeter

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Background

All current lunar digital elevation models (DEMs) have different characteristics, and thus different strengths and weaknesses (see Table 1). Currently, the most complete, highest-resolution, and highest-precision lunar DEM is the SLDEM2015 (see Figure 1 below). This was made by combining stereo imagery from the Kaguya Terrain Camera (TC) with altimetry from LOLA geolocated with the latest lunar GRAIL gravity field. The SLDEM2015 uses the TC DEM, after co-registering to the LOLA ground tracks in 1°x1° grid cells, to fill in the gaps between the LOLA tracks, obviating the need for interpolation in the LOLA DEM as is standard practice. The strengths of this DEM make it suitable for global studies of features with sizes down to ~100 m. However, some artifacts remain due to uncertainties in the SELENE orbit, the vagaries of stereophotogrammetry, and details of the co-registration method.

We have begun an effort to improve upon the SLDEM2015 by co-registering the individual TC ground swaths to the LOLA data, rather than the 1°x1° grid cells, and by leaving out the LOLA tracks from the final product, rather than keeping them in it. **Here we demonstrate that this approach removes seams between the grid cells and removes the "streakiness" that appears in some areas (see Figures 2 & 3 at right).**

Table 1: Summary of (near-)global lunar DEMs' vertical accuracy, precision, and horizontal resolution. Relative precision is the approximate typical 1σ noise over flat terrain. Effective resolution is defined as the typical size of the smallest resolvable crater. ppd = pixels per degree.

LOLA DEM 512 ppd	LRO WAC GLD100 [2]	SLDEM2013 [3,4]	SLDEM2015 [1]
Absolute accuracy: ~1 m Relative precision: ~5-10 cm Pixel scale: 512 ppd (~60 m at equator) Effective resolution: ~150 m in latitude, ~500 m in longitude at equator Coverage: ?% filled pixels -90° to 90°. Typical gap width ~500 m at equator. Consistency: Uniform quality (< 1% noise points)	Absolute accuracy: ~1 m Relative precision: ~20 m Pixel scale: 100 m per pix Effective resolution: ~1 km Coverage: -80° to 80° Consistency: Uniform quality	Absolute accuracy: ~1-10 m Relative precision: ~5 m Pixel scale: 3600 ppd (~8 m at equator) Effective resolution: ~100 m Coverage: -87° to 87° Consistency: Highly variable due to pre-GRAIL gravity field and degraded geolocation during Kaguya Extended Mission.	Absolute accuracy: ~1 m Relative precision: ~3-4 m Pixel scale: 512 ppd (~60 m at equator) Effective resolution: ~100 m Coverage: -60° to 60° Consistency: Variable due to degraded geolocation during Kaguya Extended Mission.

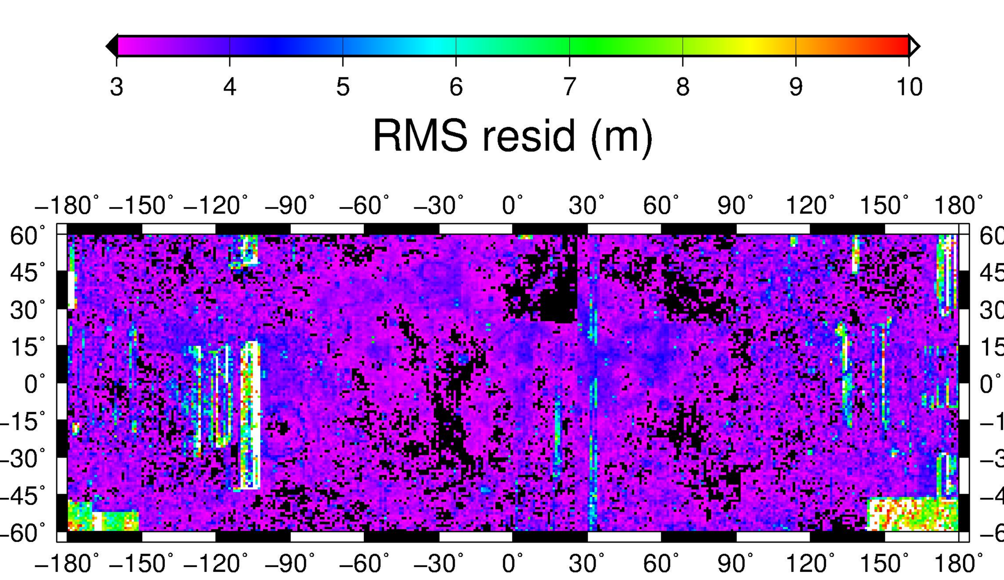


Figure 1: RMS residual between SLDEM2015 and LOLA altimetry in 1°x1° grid cells. The median value is 3.4 m and the 90th percentile is 5 m. Regions of unusually high RMS are due mostly to errors in Kaguya orbit and attitude reconstruction during its Extended Mission in 2009.

Methods

To co-register the TC data, we adopt the NASA Ames Stereo Pipeline (ASP) routine, pc_align, which uses an iterative closest point algorithm to find the best-fit transformation between the TC DEM and LOLA point cloud by minimizing the 3-D cartesian distances between them. The inverse transformation is then applied to the TC DEM to bring it onto the LOLA geodetic frame, and then it is downsampled to 512 ppd. This is done separately for each TC ground swath segment, typically a little more than 1° wide and long. Then, all the transformed swaths are mosaicked together with the ASP routine, dem_mosaic, which employs a Gaussian weighting scheme as a function of distance from center. Total processing time for the 40 TC swaths comprising Figure 2 was ~6 hours on 10 cores.

Future work will investigate the feasibility of recomputing the original TC stereo models during the Kaguya Extended mission, which could improve the data quality near Orientale and South Pole Aitken, and other isolated strips with high RMS residual in Figure 1 above. This will leverage the results of our ISFM 'Kaguya Geometric Restoration' project (formerly PDART), for which members of our group are working to improve the Kaguya Extended Mission orbit reconstruction, and for which the USGS is developing an ISIS camera model for the TC. We will employ the resources of GSFC's ADAPT high performance computing cluster.

Von Karman Crater

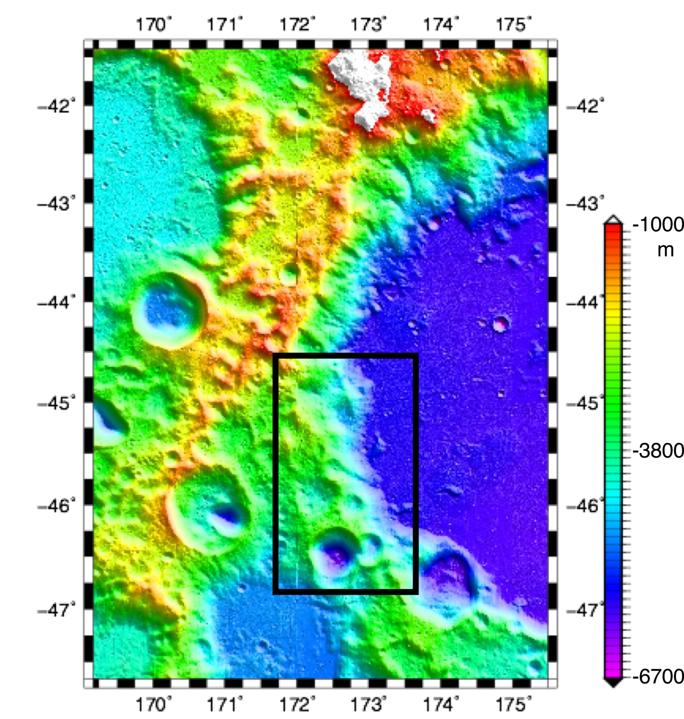
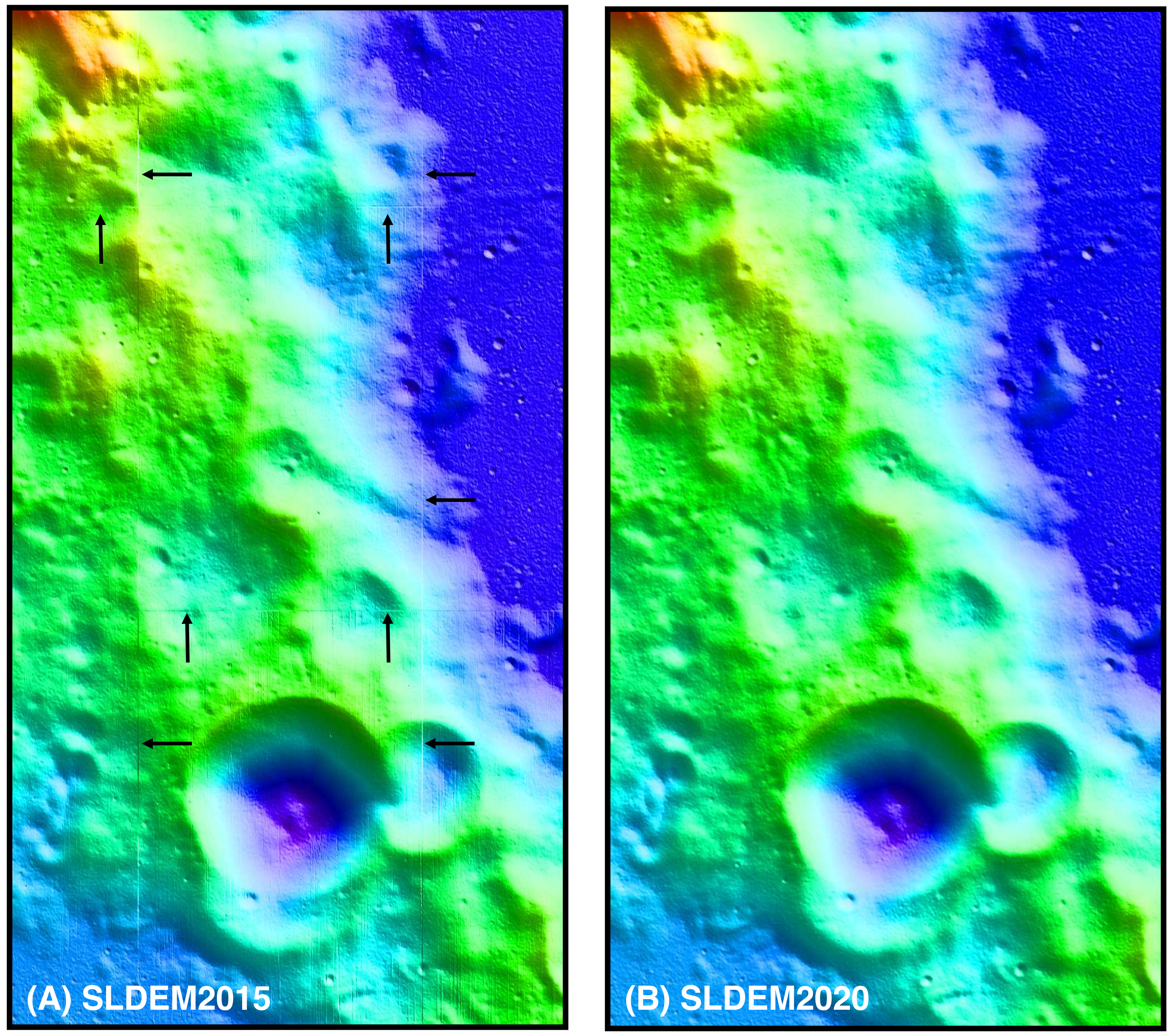


Figure 2: The two panels at right show a close-up of the inset box above for (A) SLDEM2015 and (B) SLDEM2020 using the new methods described here. Black arrows point to visible seams in SLDEM2015, which are absent in SLDEM2020. These are examples of the worst (largest) seams in SLDEM2015; the majority are within the ~3-4 m noise level.



Apollo 17 - Taurus Littrow Valley

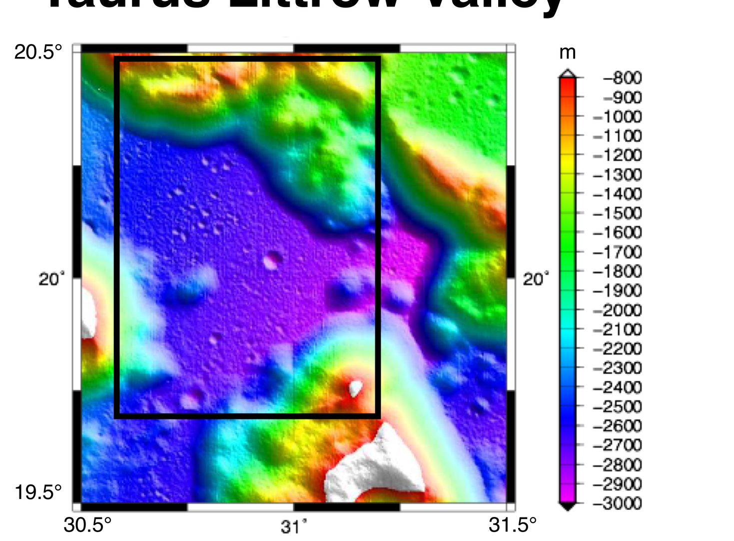
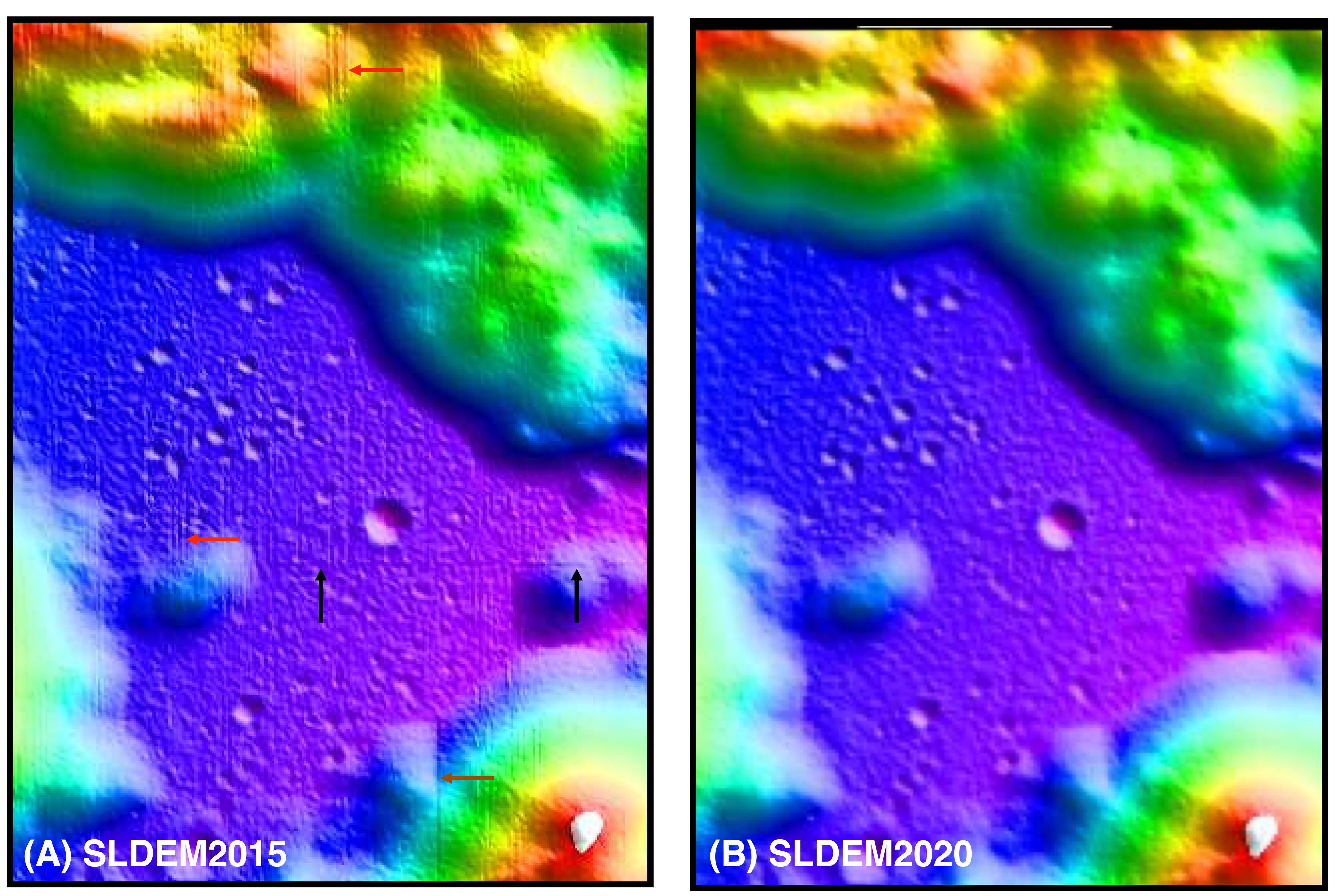


Figure 3: The two panels at right show a close-up of the inset box above for (A) SLDEM2015 and (B) SLDEM2020 using the new methods described here. Black arrows point to a visible horizontal seam and red arrows to ground tracks in SLDEM2015, which are absent in SLDEM2020.



References: [1] Barker, M. K. et al.(2015) Icarus, in press. [2] Scholten, F. et al. JGR, 2012, 117, E12. [3] Haruyama, J. et al. (2014) LPSC 45, #1777. [4] SELENE Data Archive site, http://l2db.selene.darts.isas.jaxa.jp/archive/index.html.en